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TECHNIQUES OF SPRUCE BUDWORM SURVEYS IN THE NORTHERN ROCKY MOUNTAIN REGION 1960

Progress Report

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Division of Forest Insect Research

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INTRODUCTION

Annual surveys of spruce budworm[1] infestations in Douglas-fir stands in the northern Rocky Mountain Region have been made since 1950. Until 1955 the surveys were made almost entirely from the air. In 1955 ground surveys were used to supplement aerial surveys by mapping areas of defoliation not visible from an airplane. Outbreak areas continued to expand and by 1958 nearly all the Douglas-fir timber type in south central Montana was infested. During this period the usefulness of aerial surveys lessened. Ground survey coverage was increased and rough estimates of defoliation were made. Sampling methods were improved but estimates of foliage damage alone were found deficient. They recorded past events and did not provide a basis for predicting the trend of the outbreak.

In 1956 and 1957 the Forest Insect Laboratory sampled budworm population in the overwintering larval stage to supplement the damage estimates of the previous year[2].

Measurements of overwintering larval population were used to predict the presence and relative abundance of budworm in proposed control areas in prior to aerial spraying. Surveys of overwintering larvae proved that defoliation was not a good indicator of budworm population that might be present the next season--heavy populations of overwintering larvae were often found in areas of light defoliation in an expanding infestation.

1/ *Choristoneura fumiferana* (Clem.)

2/ Terrell, Tom T. Sampling populations of overwintering spruce budworm in the northern Rocky Mountain region, Research Note No. 61, U. S. Department of Agriculture, Forest Service, Intermountain For. and Range Exp. Station, Ogden, Utah. 1959. 8 pp. illus.

All this pointed to the need for a better means of measuring the budworm population in addition to surveys of foliar damage.

In 1959 a study was started to determine if other life stages of budworm in Montana could be effectively sampled. An estimate of budworm population made during a current season might provide a means of predicting foliar damage during the following year.[3]

METHODS

Twenty-five permanent sample plots were established in 1959 from which annual samples of budworm population and foliar damage were to be taken. The plots served the dual purpose of providing data to evaluate budworm activity in the region and furnished the basis of a study to determine the relationship between current budworm population and foliar damage during the succeeding year.

Each plot consisted of five or more intermediate Douglas-fir trees in an even-canopied stand. The plots were distributed through the infested areas in Montana to give a representative sample of the outbreak areas (figure 1).

The plots were first established to measure overwintering larvae and sample trees were felled. Overwintering larvae proved inferior as a sample of the population and a new set of trees were marked for subsequent sampling. Each plot tree was numbered to permit comparable samples to be taken annually from the same trees.

In 1959, four samplings were made on the plots: overwintering larvae, moths, egg masses, and defoliation. In 1960 these were reduced to the last three, and the following procedures were used in sampling:

Moths.--In late July and early August when the budworm was in the pupal stage, four 15-inch twigs were clipped from midcrown from each plot tree. Budworm pupae were collected from each twig and placed in a two-ounce glass jar with a bit of foliage. In some instances moths had emerged prior to the time of collection. The vacated pupal cases were collected and recorded as moths when the cases showed evidence of successful moth emergence. The collection jars were brought in to the Laboratory and held for emergence of the moths. A record of parasitism in the pupal stage was obtained by this type of collection.

3/ Terrell, Tom T., David G. Fellin. Study of techniques of spruce budworm surveys in the northern Rocky Mountain region: 1959 progress report. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Exp. Station, Ogden, Utah. July 1960. 14 pp. (processed).

A sequential sampling plan was used during the collection of pupae in 1960. The sampling plan was developed by Walter E. Cole, of the Intermountain Station, from pupal case data collected by the Laboratory in 1959 (table 1).

Defoliation.--The foliar damage caused by larval feeding was recorded at the time the pupae were collected. The same technique was used in 1960 as in 1959: Each plot tree was viewed through 9 X 35-power binoculars at close range. Individual buds and needles could be clearly seen. Preparation in estimating defoliation was made by clipping typical limbs from various parts of the infested trees with pole pruners. The actual percentage of defoliation was then determined on these limbs by averaging the amount of defoliation of 50 or more shoots. The foliage adjacent to the cut limbs was then viewed through binoculars to fix in mind the appearance of that particular percentage of defoliation. After a few hours of such practice one becomes adept at estimating defoliation with considerable accuracy. Periodic checks thereafter were necessary to avoid a tendency to underestimate defoliation. Severe defoliation is easiest to estimate; light defoliation is more difficult.

In practice, estimating was done by a process of elimination: the estimator viewed the foliage through the binoculars and decided first, is the defoliation more or less than 50 percent? If more, the next decision was, is it more or less than 75 percent? This process was continued until the amount of defoliation was estimated to fall on or between these 25 percent steps. Where defoliation was estimated at more than 25 percent, between step estimates were usually recorded at mid-step intervals of $37\frac{1}{2}$ percent, $62\frac{1}{2}$ percent, or $87\frac{1}{2}$ percent. In lighter defoliation closer estimates were made. Estimators were free, however, to record the defoliation at any percentage they felt to be appropriate. Often the percentage arrived at while checking the actual defoliation in some part of the crown was recorded.

Following the practice used in 1959, defoliation for each tree was estimated by crown thirds: upper crown, midcrown, and lower crown. The estimates for the crown thirds were then weighted by the multipliers 1, 3, and 5 for upper, middle, and lower crowns, respectively, to compensate for the greater amount of foliage in the middle and lower crown. The product was then divided by the sum of the multipliers (9) to obtain the weighted average for each tree.

An analysis of the data on defoliation taken by crown thirds in 1960 indicated midcrown estimates would have been sufficient. The details of this analysis will be given later in the report.

Egg mass.--During early September, foliage for egg mass counts was collected from the plot trees. There was some deviation from the methods used in 1959. In 1959, two limbs were cut from opposite sides of each tree. The foliage was removed and discarded from one side of each limb. The remaining foliage on the limb was measured for length and width. Half the product of the length times the width in square inches was used as the foliage area. Because many of the midcrown limbs were quite small this method resulted in some rather small samples.

In 1960 more uniform samples were obtained and better measurements were made. A piece of canvas about 4 feet square was spread on the ground where the foliage was collected. Enough limbs were cut from midcrown from one side of the plot tree to roughly cover the canvas. All the foliage was removed from the limbs and placed in an 18- by 30-inch plastic bag. The process was then repeated for the opposite side of the tree. Each plot gave 10 of these samples.

In 1959 a few samples of foliage were placed in plastic bags and stored in a cold room in a creamery. These samples remained fresh for a considerable time. In 1960 all the samples (250) were collected and brought to Missoula, Montana and were stored in a cold room maintained at about 38° F. The greatest length of time between collection and storage was four days.

After the foliage samples had been collected and stored, a crew of four women were trained to examine the foliage and remove the egg mass-bearing needles. As the samples of foliage were brought into the Laboratory from storage they were spread on a black, 4- by 8-foot canvas marked off in gridiron fashion. The area in even hundred square inches was marked at each line. The foliage was evenly spread on the canvas starting from and end mark. The square inches covered was easily determined and recorded for the sample. The foliage was then piled in the middle of the canvas and each crew member removed a few twigs at a time and examined them for egg masses. The twigs were clipped into 3- to 4-inch lengths for easy observation. The examined foliage was discarded into a separate carton for each crew member. All needles with any foreign material were removed. by the examiners and placed in a petri dish. When all the foliage of the sample had been examined the petri dishes containing the needles removed were passed to an entomologist who separated the needles bearing egg masses from those with other matter on them. A rather large number of needles had various scale insects, aphid eggs, pitchy spots, bird droppings, and other objects attached to them. The examining crew was not required to differentiate between egg masses and other foreign objects with the exception of pine needle scale. After a day's experience, needles with pine needle scale, which were very plentiful, were not removed. To continue removing such needles would have been too time consuming for both the crew members and the entomologist.

The entomologist directed the crew, trained the workers, measured the foliage, kept all the records on the samples, and made periodic checks of the discarded foliage. He also placed the needles having egg masses in No. 000 gelatin capsules with a label denoting the plot number, tree number, and sample side.

The foliage examination was completed in three weeks and required $82\frac{1}{2}$ working days.

In 1959, 162,710 square inches of foliage were examined during the egg mass survey; in 1960, 441,800 square inches were sampled. The 1959 samples averaged 678 square inches of foliage; in 1960 the samples were more uniform and much larger, averaging 1,767 square inches per sample.

In 1960 all the examination was done in the laboratory under fluorescent over-head lights supplemented with individual desk lamps. In 1959 part of the work was done outdoors in sunlight, but inclement weather required the crew to move inside. Weather in Montana in late September often is not suitable for outside work of this kind.

When all the foliage samples had been examined the entomologist separated the new (1960) from old (prior to 1960) egg masses. This separation is the most difficult phase of the work. Most egg masses are easily identified as to new or old. Several criteria were used to classify the egg mass: condition of the edges of the overlapping egg plates, and color were most useful. About 10 percent of the egg masses, however, were difficult to classify.

An aid to the classification of borderline masses was made by selecting about 40 egg masses deposited in 1960 on new needles. New needles are easily identified because they shrink and have a dimpled light green skin. Egg masses on these needles are positively classified as new. The egg masses used as a standard were in various states of deterioration. These egg masses were glued to a card for handy reference. Questionable egg masses were compared to those on the card and classed as old if their condition indicated greater deterioration.

After the first separation, a second examination was made by the entomologist. A third and final examination was made by a second entomologist to assure that the best separation possible was made. There were 1,601 egg masses classed as new in 1960.

RESULTS

In 1960 several refinements were made in the methods of sampling budworm population from that used in 1959. In every instance, however, the data obtained in 1960 were comparable to related data of 1959. The results of the various techniques used in 1960 are given in the order presented under methods.

Moths.--Collecting pupae from the 15-inch twigs and holding them in 2-ounce jars worked out very well. A sequential sampling system was used in the collection of pupal cases, but, later, mortality from parasitism and other causes during rearing affected the final results of sequential sampling.

By holding the pupae in rearing jars a record of parasitism was obtained. This record is incomplete, however, because some of the pupal cases had been vacated before collection. In some instances several parasites emerged from a single pupa. A total of 606 pupal cases and pupae were collected during the sampling. About 20 percent of the pupae had been parasitized. Where the parasites could be identified, they were 29 percent *Phaeogenes* sp., 42 percent other hymenopterus species, and 29 percent dipterous sp.

The final data on moths per 15-inch twig from 24 plots in 1960 (one plot was sprayed during a control project and was therefore eliminated for this comparison) gave an average of $.97 \pm 25$ percent per twig. This compares with 1.11 ± 22 percent moths per twig in 1959.

Defoliation.--Defoliation was measured by crown thirds as described under methods. An analysis of the data from the crown thirds shows that midcrown samples do not differ significantly from the average for the whole tree. There were, however, greater differences between both the upper and lower crown samples and the tree average. Some additional data were taken on defoliation measurements. Thirty-one 5-tree samples were tested for difference between midcrown samples and the tree average. A value of $t = .63$ was obtained which indicated no significant difference between midcrown defoliation and the tree average.

Data recorded on defoliation in 1959 were then checked and the results were similar. These data indicate that measurements of defoliation taken at midcrown would be adequate. This would save some time per plot in the field and simplify the processing of data later.

Defoliation in 1960 averaged 34 percent of the new needles compared to 38 percent in 1959--the difference is not significant. However, from field observations, shoot growth appeared to be less in 1960 than in 1959. If the foliage growth proved to be less in 1960 and the percentage of defoliation was about the same for both years, it would mean that less foliage had been eaten in 1960 by budworm larvae.

Shoot growth for 1959 and 1960 were later measured for all the plots by picking samples of foliage at random from foliage collected for egg mass counts. The measurements were made on 10 twigs from each sample (100 from each of the 25 plots). Shoot growth was less in 1960 in 24 of the 25 plots. Only one plot, in Yellowstone National Park, showed better growth in 1960 than in 1959.

If there is much variation in shoot growth length from year to year, estimates of defoliation alone lose some value as a measurement of both damage to the timber stand and of budworm population level. Perhaps some weight should be given to foliage growth in estimates of defoliation. The following table will give the foliage growth for 1959 and 1960 and illustrate the result of comparing defoliation and shoot growth:

	Defoliation (percent)	Shoot growth (inches)	Growth destroyed (inches)	Net growth of shoots (inches)
1959	38	.81	.31	.50
1960	34	.60	.20	.39

An insignificant decrease was indicated in the percentage of defoliation in 1960 compared to 1959. In terms of inches of new shoot growth destroyed, the decrease of budworm activity was greater.

Egg masses.--Considerable work was done with egg masses in 1960 and some interesting results were obtained.

Egg masses were first used as a measure of budworm population in this region in 1959. Both "old" and "new" egg masses were collected from samples of foliage. The old egg masses were thought to represent masses deposited in 1958 and the new were those deposited in 1959. If old and new egg masses represented the egg population for each of the two years, comparing them would show the trend of the infestation. Some loss of old egg masses was presumed to have occurred during the preceding winter, but this loss was considered offset by some few egg masses remaining from 1957. There was some question, however, as to the validity of comparing old and new egg masses without knowing how many were lost during the preceding year or how many might remain for a longer time.

In 1960 foliage samples for egg mass estimates were collected from the same plot trees as in 1959. Both old and new egg masses were again removed. The old egg masses per unit of foliage in 1960 should approximate the new egg masses of 1959 if all old egg masses were representative of those deposited in the preceding year. There were far fewer old egg masses per 1,000 square inches of foliage in 1960 than new egg masses in 1959. The loss measured from 24 plots was 60 percent (from 10.36 masses per 1,000 square inches in 1959 to 4.10 per 1,000 square inches in 1960). Reductions between 1959 new masses and 1960 old masses occurred on 21 of the 24 plots. The only plots showing a comparable number were very low in masses for both years.

While the evidence is clear that a great many egg masses are shed or removed from the needles during the year it also appears that in some instances they will remain for several years. "Old" egg masses were collected from a plot in both 1959 and 1960 that has shown no evidence of infestation for the two years it has been established. No moths, defoliation, or new egg masses were found on this one plot in either 1959 or 1960.

From the comparisons made in 1960, it appears erroneous to use old egg masses as representing those of the previous year in this region. A trend in the infestation cannot be made by a single sampling of foliage and recording the "old" and "new" egg masses.

Egg masses vary in size from 1 to 15 mm. in length in this region. Large egg masses have a great many more eggs than the small ones. The variation in egg mass size and consequently in the number of eggs raised a question as to whether egg masses were a valid substitute for eggs as a measure of the population. There is the possibility that a female moth in ovipositing her complement of eggs might deposit one or two large masses of eggs or a great many small ones.

A comparison was made between egg masses and eggs by converting all the egg masses to eggs by measurement. One hundred and seventy-one egg masses of various lengths were removed from the needles and the egg cells were counted from the underside of the mass. Egg masses one millimeter in length were few; they had either 1 or 2 eggs. In the 2nd millimeter 2 to 4 eggs were deposited and each succeeding millimeter averaged 7 eggs. Most egg masses were 5 egg cells wide at mid-point but some few would vary from 2 to 7 cells wide. The plotted data in figure 4 show the consistency of average eggs per egg mass for various lengths. From these data a simple formula was developed to determine eggs per mass for all lengths above one mm.: eggs equal (length (mm.) X 7) - 9.

All the new egg masses from the 1960 foliage samples were measured and converted to eggs. Eggs and egg masses were then compared to determine if egg masses were a valid measurement of budworm population. The best test of these data would be to make a regression analysis between egg masses and defoliation and between eggs and defoliation. However, the defoliation resulting from this population will not occur until midsummer 1961.

The problem was approached by assuming that if moths were irregular in depositing their complement of eggs in a few or many egg masses, a correlation between egg masses and eggs would not be as good as it would be if the moths were consistent. Consistency in depositing both small and large egg masses in about the same proportion in all plots should produce a very close correlation between egg masses and eggs. A correlation coefficient of $r = .997$ was obtained where r at 1 percent equals .515. This extremely close correlation indicates that egg masses are a very good measure of the population. There is, therefore, no advantage in converting egg masses to eggs.

All the new egg masses collected in 1959 were measured to determine if there had been a difference in the eggs per mass in 1959 and 1960. There was no significant difference: in 1959 the masses averaged 42.0 eggs and in 1960, 40.8 eggs.

As stated earlier, the purpose of this study was to devise methods of measuring spruce budworm population during one or more of its life stages and relating that population level to subsequent defoliation. When this relationship is established a means of predicting foliar damage will be available.

In 1959 two life stages, moth and egg, appeared to be the most promising for population measurement. The moth stage had two advantages: population estimates were easily made and the results were quickly available. Moth population estimates correlate very well with subsequent damage (figure 2). The relationship between moth population and subsequent defoliation was found to be curvilinear. At least a better fit was found than in a straight line relationship. The multiple regression coefficient in the regression in figure 2 is, r equals .789 where r at 1 percent is .537. This indicates that the correlation between moths and defoliation is highly significant.

Budworm moths are two life stages removed from the larval stage that will cause defoliation: the egg and hibernating larval stage. There are also several intervals between moth emergence and defoliation: moth flight, the embryonic period, larval migration to hibernation, overwinter hibernation, and larval migration to the foliage. Mortality in these stages and intervals normally decrease the population drastically. An abnormal decrease in any of these periods would influence a prediction made on the basis of population. It is therefore reasonable to assume that a greater risk is taken when a prediction is based upon a population stage farther removed from the eventual defoliation than is taken when the prediction is based upon a later stage.

In 1960 the relationship between moths and the egg masses they deposited was not the same as the relationship between moths and eggs in 1959. There was a considerable decrease in eggs in 1960. In 1959, 1 moth per 15-inch twig deposited an average of 9.3 egg masses per 1,000 square inches of foliage. In 1960, with very nearly the same moth population, the ratio of moths to egg masses was 1 to 3.8. It appears obvious that a prediction of 1961 defoliation based upon the relationship between moths in 1959 and defoliation in 1960, as shown in figure 2, would be invalid because the moths deposited fewer eggs in 1960. Moth population therefore seems of doubtful value as a basis for predicting future defoliation.

Egg masses as an index of budworm population are closer to the larval population that will cause deoliation. Egg masses also correlate well with defoliation (figure 3). The relationship is curvilinear as shown in the regression. The multiple regression coefficient, r equals .695 where r at 1 percent equals .515 indicates a highly significant correlation between egg masses and defoliation. The eggs are the last stage in which the budworm can be readily measured during the season. A prediction of defoliation based upon egg mass population will probably always be most reliable. The hazard of flight mortality to moths is past when the egg stage is reached. Flight loss or mortality may be a very important factor.

There will always be some uncertainty in forecasting future activity due to unpredictable happenings between one season and the next. At present an annual survey of budworm egg masses appears to provide the best estimate of population on which to estimate the trend of the infestation and to predict the foliar damage in the following year.

CONCLUSIONS

Estimates of the amount of defoliation are a handy means of measuring budworm activity; however, unless foliage growth is considered, the results may be misleading. Defoliation is not a valid means of estimating budworm population of the succeeding generation or of predicting the trend of the outbreak.

Variations in budworm population from year to year are best for indicating the trend of an infestation. Of the several life stages that may be used for population sampling, the moth stage and egg stage appear to be best.

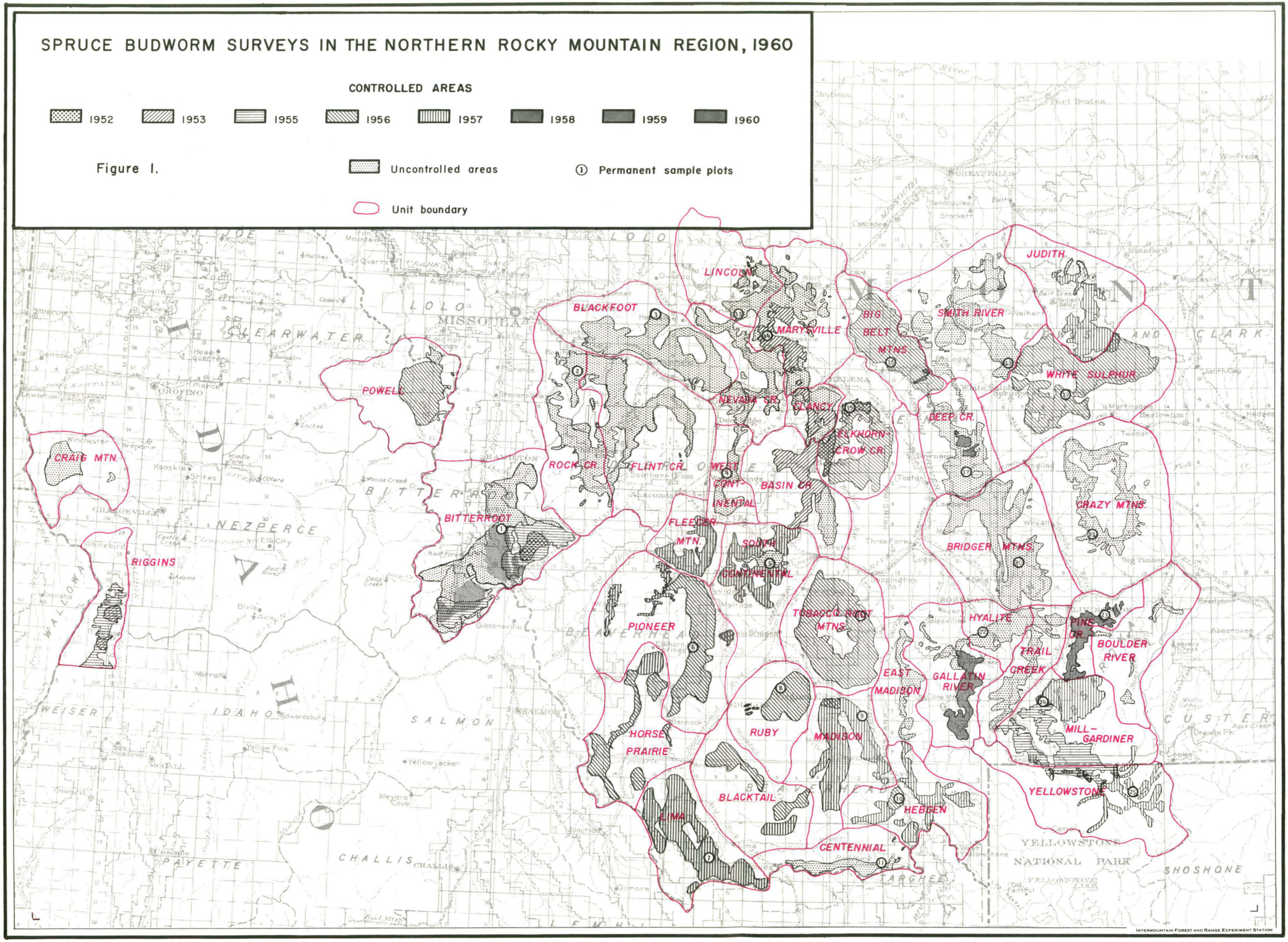
Sampling the population in the moth stage is relatively easy and results are quickly available. Moth population correlates with subsequent defoliation, but mortality during the flight period may upset an estimate of future defoliation based upon moth population.

Surveys of budworm population in the egg stage are more difficult and costly than moth surveys, but they are thought to be more reliable. Egg masses are as useful as eggs for the purpose of estimating population. Old egg masses do not represent an accurate index of the preceding year's egg mass population. Many masses are lost during the year but some persist for several years.

An estimate of budworm population in the egg mass stage appears to be the best for indicating the trend of an outbreak from year to year and for predicting defoliation during the subsequent season.

Table 1.--Sequential table for field use in collecting of spruce budworm pupae to sample the moth population

Number of twigs examined		Class I	vs.	Class II		Class II	vs.	Class III		Class III	vs.	Class IV	
10				7		7						39	
11		1		7		8						42	
12		1		8		9		20		21		45	
13		2		8		11		21		24		48	
14		2		8		12		23		26		50	
15		2		9		13		24		29		53	
16		3		9		14		25		32		56	
17		3		9		16		26		35		59	
18		3		10		17		28		37		61	
19		4		10		18		29		40		64	
20		4		10		19		30		43		67	
21		4		11		20		31		46		70	
22		5		11		22		33		48		72	
23		5		11		23		34		51		75	
24		5		12		24		35		54		78	
25	Class I	6	Continue Sampling	12	Class II	25	Continue Sampling	36	Class III	56	Continue Sampling	81	Class IV
26		6		13		27		38		59		83	
27		6		13		28		39		62		86	
28		7		13		29		40		65		89	
29		7		13		30		41		67		92	
30		8		14		32		42		70		94	
31		8		14		33		44		73		97	
32		8		15		34		45		76		100	
33		9		15		35		46		78		103	
34		9		15		36		47		81		105	
35		9		16		38		49		84		108	
36		10		16		39		50		87		111	
37		10		17		40		51		89		114	
38		11		17		41		52		92		116	
39		11		17		43		54		95		119	
40		11		18		44		55		98		122	



SPRUCE BUDWORM SURVEYS IN THE NORTHERN ROCKY MOUNTAIN REGION, 1960
CONTROLLED AREAS
1952
1953
1955
1956
1957
1958
1959
1960
Uncontrolled areas
Permanent sample plots
Unit boundary
LINCOLN
BLACKFOOT
MARYSVILLE
BIG BELT MTNS
SMITH RIVER
JUDITH
WHITE SULPHUR
POWELL
CRAIG MTN.
NEVADA CR.
CLANCY
ELKHORN-CROW CR.
DEEP CR.
ROCK CR.
FLINT CR.
WEST CONTINENTAL
BASIN CR.
CRAZY MTNS.
BITTERROOT
FLEECER MTN.
SOUTH CONTINENTAL
BRIDGER MTNS.
RIGGINS
PIONEER
TOBACCO ROOT MTNS.
HYALITE
PINE CR.
BOULDER RIVER
TRAIL CREEK
EAST MADISON
GALLATIN RIVER
HORSE PRAIRIE
RUBY
MADISON
MILL-GARDINER
YELLOWSTONE
BLACKTAIL
LIMA
HEBGEN
CENTENNIAL
YELLOWSTONE NATIONAL PARK
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Figure 1.

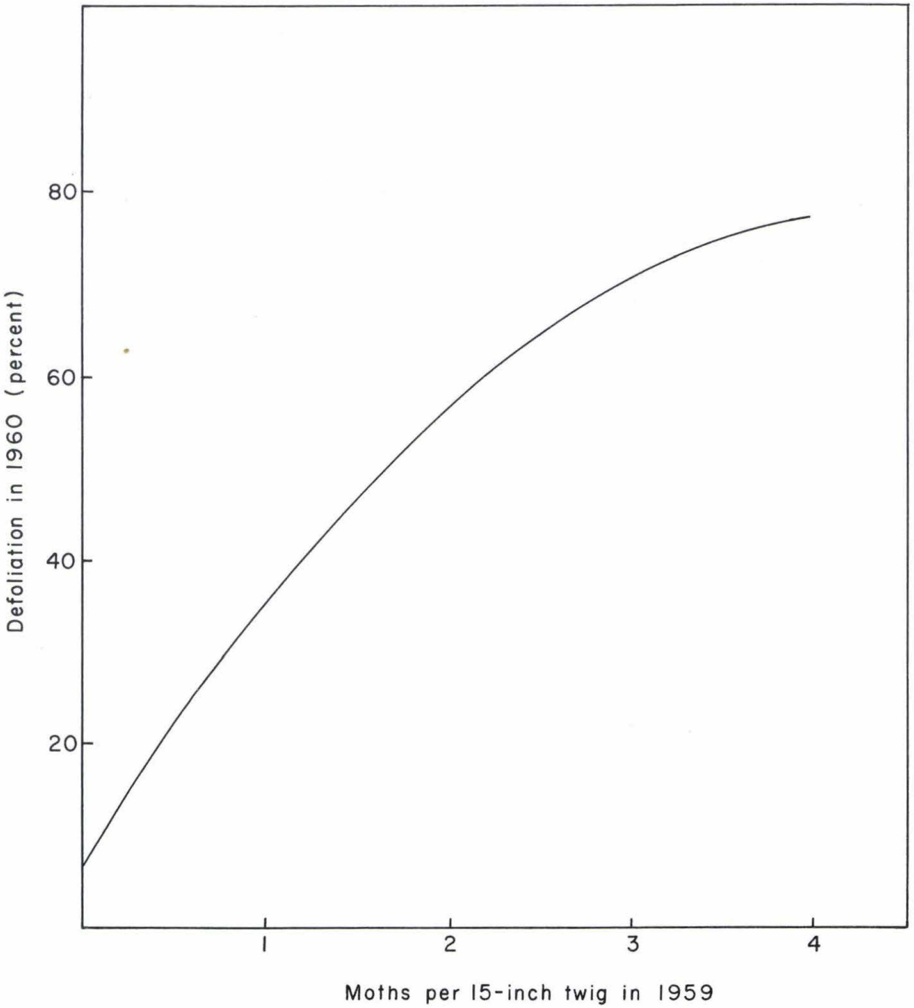


Figure 2.--Relationship of moths to defoliation

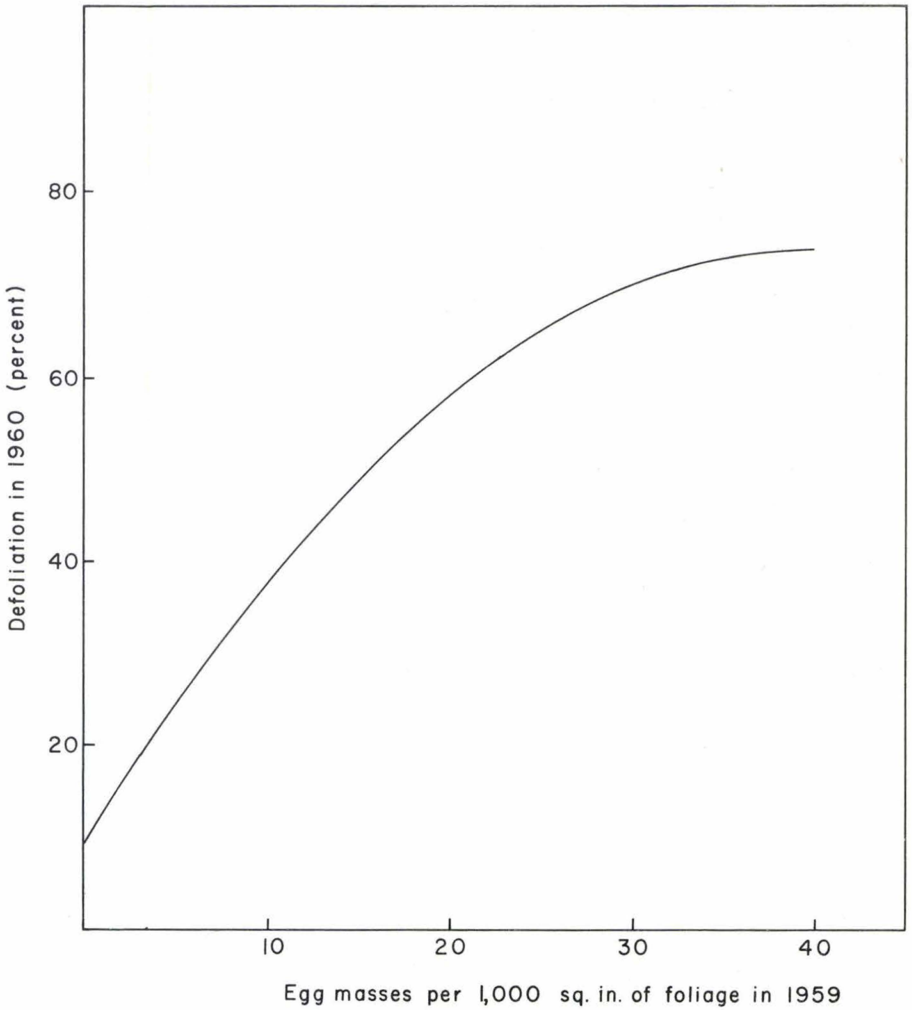


Figure 3.-- Relationship of egg masses to defoliation

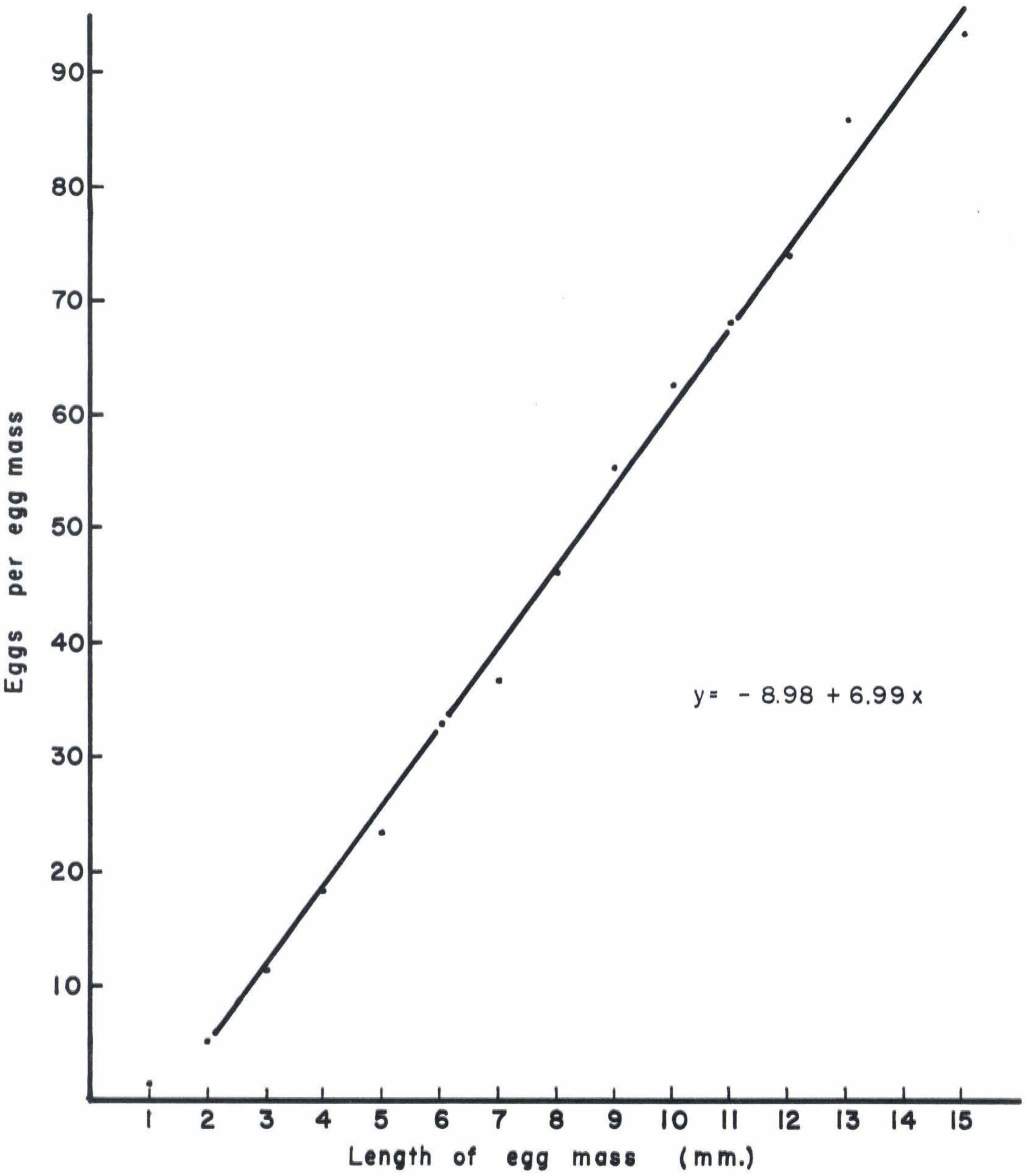


Figure 4.-- Relationship between the number of spruce budworm eggs and the length of the egg mass